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REMOTE AND CLOSE SENSING OF FTES AND OTHER COHERENT MAGNETOPAUSE STRUCTURES

FINAL REPORT

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FINAL TECHNICAL REPORT

Remote and Close Sensing of FTEs and Other Coherent Magnetopause Structures

I. Introduction

The research, conducted under NASA Grant NAG5-3031 and summarized here, has been concerned with two specific problems in the area of the small-scale and mesoscale structure of the magnetopause and related data analysis techniques:

(1) Recovery of two-dimensional internal magnetopause structures by use of data from a single spacecraft penetrating the magnetopause;
(2) Minimum-variance analysis and deHoffmann-Teller frame analysis with special emphasis on new error estimates.

The following articles, in which the research performed is described in detail, have been published or submitted for publication. Each article contains acknowledgment of support or partial support from NAG5-3031. They are appended to, and form part of, this Final Report.

1. Sonnerup, B.U.Ö., and M. Guo, Magnetopause transects, *Geophys. Res. Lett.*, *23*, 3679-3682, 1996.
2. Sonnerup, B.U.Ö., and Maureen P. Scheible, Minimum and maximum variance analysis, submitted to *Handbook of Multispacecraft Data Analysis*, to be published under the auspices of the International Space Science Institute (ISSI), Bern, Switzerland, 1997.
3. Khrabrov, A.V., and B.U.Ö. Sonnerup, deHoffmann-Teller analysis, submitted to *Handbook of Multispacecraft Data Analysis*, to be published under the auspices of the International Space Science Institute (ISSI), Bern, Switzerland, 1997.

These articles are referred to as Papers 1 - 3 in the discussion contained in Section II.

Results from the research have also been reported at the following scientific meetings:

- AGU Fall Meeting, San Francisco, California, December 1995: poster paper by M. Guo and B.U.Ö. Sonnerup entitled: "Two-Dimensional Structures in the Magnetopause" (SM41A-08).
- COSPAR Meeting, Birmingham, England, July 1996: invited paper by B.U.Ö. Sonnerup entitled "What do we really know about the magnetopause" (DD.1-0025).
- EGS First Alfvén Conference, Kiruna, Sweden, September, 1996: invited paper by B.U.Ö. Sonnerup entitled "The Magnetopause/Low-Latitude Boundary Layer Region".
- AGU Fall Meeting, San Francisco, CA, December, 1996: Contributed oral presentation by M. Guo and B.U.Ö. Sonnerup entitled: "Magnetopause Transects" (SM 41C-08).
- Data Analysis Workshop, International Space Science Institute (ISSI), Bern, Switzerland, March 1996 and January 1997: Presentations by B.U.Ö. Sonnerup on "Minimum Variance Analysis" and on "DeHoffmann-Teller Analysis".

II. Discussion of Research Performed

Brief synopses and highlights of the individual research projects supported by Grant NAG5-3031 are given below.

II.1 Internal 2D Magnetopause Structures

We have developed a new data analysis technique which allows us to recover two-dimensional coherent structures within the magnetopause from data taken by a single spacecraft as it passes through the current layer, from the magnetosphere to the magnetosheath or vice versa (Paper 1).

The basic assumptions of the technique are that the structures are quasi-two-dimensional, that they do not change significantly during the magnetopause crossing time, and that they are convected in a frozen manner with the plasma. These assumptions imply that, in a frame moving with the structures, they are magnetohydrostatic equilibria of the tangential discontinuity (TD) type governed by the so-called Grad-Shafranov equation (Eq. 2 in Paper 1). We have developed a numerical Grad-Shafranov solver which uses magnetic-field and plasma data, taken along the spacecraft trajectory line through the structures, to calculate the three magnetic-field components and the plasma pressure in a rhombic region surrounding the spacecraft trajectory and having the trajectory as one of its diameters. An example of the outcome of such a field-map reconstruction (a "magnetopause transect") is given in Fig. 5 of Paper 1. Two significant new features found for this TD-type magnetopause structure is the appearance of a magnetic island with an X-type magnetic null on each side as well as a narrow region of weak magnetic flux (a "worm hole") that appears to magnetically connect the magnetosheath to the magnetosphere.

The technique has now been applied to a second magnetopause crossing that appears to meet the model criteria but there is a need for more extensive application in order to assess the utility of this type of field-map reconstruction. It is noted that the method should also be applicable to 2D structures other than the magnetopause, for example, flux ropes in the geomagnetic tail or in the solar wind ("magnetic clouds"). Extension of the technique to dynamic equilibria such as RDs observed during magnetopause reconnection events is possible since equilibria involving field-aligned flow are also governed by an equation of the Grad-Shafranov type. This is also the case for flow transverse to the magnetic field in the low-latitude boundary layer where it should be possible to recover structures such as vortices.

II.2 Minimum Variance Analysis/deHoffmann-Teller Analysis

We have participated in a set of workshops at the International Space Science Institute (ISSI) in Bern, Switzerland, which had the goal of producing a handbook on multispacecraft data analysis techniques for use in connection with the CLUSTER Mission. We have written two chapters for this book which are currently undergoing peer review. These chapters represent the main research effort performed under the grant.

The chapter entitled "Minimum and Maximum Variance Analysis" (Paper 2) contains a review of the basic features and applications of this type of data analysis, with special emphasis on error estimates and on optimal data selection. We have derived a new set of simple analytical error estimates (Eqs. 9.23 and 9.24 of Paper 2) which appear to agree well with those obtained from the more elaborate numerical bootstrap approach. In time, these analytical estimates, which depend only on the outcome of a single minimum-variance calculation, should replace error estimates found in the earlier literature and should render recently proposed bootstrap calculations [*Kawano and Higuchi*, 1995] unnecessary in most cases.

The chapter entitled "deHoffmann-Teller Analysis" (Paper 3) contains a review of how, for a given magnetic-field and plasma velocity data set, one can find a moving frame of reference (the "deHoffmann-Teller or HT frame") in which the residual electric field is a minimum in the least-squares sense. The main utility of such a frame is for the study of coherent magnetic and plasma structures moving past an observing spacecraft. Thus the existence of a high-quality HT frame is important for the data analysis technique discussed in Section II.1. The principal new item in this chapter is again the analytical error estimates (Eq. 10.21 in Paper 3) which provide measures of uncertainty in magnitude as well as direction of the HT frame velocity, v_{HT}.

III. References

Kawano, H., and T. Higuchi, The bootstrap method in space physics: error estimation for the minimum variance analysis, *Geophys. Res. Lett.*, *22*, 307, 1995.

IV. Personnel

B. Sonnerup (PI)
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V. Appendices

Papers 1-3, listed in Section I are appended to, and form part of, the present report.